2.1 Describing Sustainability

Figure D2.1: A mountain meadow in Banff National Park

What kind of impact could humans have on an established ecosystem like the one shown in Figure D2.1? A mountain meadow does not require people to input raw materials or to remove wastes because matter is cycled in biogeochemical cycles. Artificial lights are not required because green plants are able to transform the energy in the Sun's photons into chemical potential energy through photosynthesis. Photosynthesis provides a way for energy to be passed on to other organisms through the food chain. Since an ecosystem is capable of maintaining itself indefinitely, it is said to be **sustainable**. Barring disruption, as long as the Sun shines and matter continues to be cycled, an ecosystem like this one continues to exist.

sustainable: capable of being maintained at length without interruption, weakening, or loss of essential characteristics (such as matter and energy)

An established ecosystem stands in stark contrast to most of the current systems set up to maintain the towns and cities most people live in. In a city, matter is not cycled. This is evident in the armies of transport trucks that bring goods into the city and in the legions of garbage trucks depositing waste daily at the local landfill.

As far as energy is concerned, fossil fuels may not be dependable energy sources for future generations if society continues to consume them at the current rate. Because of the current usage patterns for materials and energy, the vast majority of human settlements in industrialized countries are described as being **non-sustainable**. These systems have the potential to break down because the supply of raw materials and the non-renewable sources of energy will eventually become exhausted.

Does it make sense to be so dependent upon resources that will one day run out? Is it appropriate for the current human population to deplete the supply of limited resources, leaving a long list of environmental problems for future generations? Should continued development of non-sustainable human systems be questioned? What are the long-term consequences of abusing Earth's life-support system?

You may hear people asking questions like these when discussing the growth of cities or the expansion of industry within your local area. These questions indicate a growing concern among people and a willingness to consider new approaches to development. Approaches that consider meeting human needs today while balancing the long-term implications, including possible harm to the environment, demonstrate **sustainable development**. Many people regard sustainable development as one of the most important ideas of our time because it is like a crossroad—the place where pressing ecological, societal, and economic issues all meet.

non-sustainable: incapable of being maintained at length due to interruption, weakening, or loss of essential characteristics (such as matter and energy)

sustainable development: the development of industrial and natural resources that meets the needs of the present generation without compromising the ability of future generations to meet their own needs

Practice

1. Two next-door neighbours utilize very different strategies when it comes to landscaping their front yards. One neighbour plants a front lawn of lush green grass that requires regular watering and fertilizer application. The other neighbour uses stone pathways that wind through a variety of drought-resistant wildflowers and shrubs that are native to the area.
   a. Explain which neighbour has the more sustainable front yard.
   b. Describe the cumulative effects of many people utilizing non-sustainable landscaping practices on both the local environment and the biosphere.
2. To some people, Earth is considered to be a fragile spaceship that is the home for humans and many other life forms. Use the notion of "spaceship Earth" to explain the importance of sustainable development.

Demonstrating Sustainable Development

One example of how a community can move in the direction of sustainable development can be found in the town of Okotoks, Alberta. Like many communities surrounding Calgary, Okotoks has experienced rapid population growth. What makes this community different is that its administrators have made a conscious decision to control the growth of the town—keeping it in step with the ability of the environment to support the population. In addition, the creative use of renewable-energy technologies within the community has attracted national and international attention. You will learn more about the sustainable development occurring in Okotoks in the next activity.

Utilizing Technology

Okotoks—Moving Toward Sustainable Development

Purpose

You will watch a video to identify and analyze examples of sustainable development that have been utilized by the town of Okotoks, Alberta.

Science Skills

- ✓ Performing and Recording
- ✓ Analyzing and Interpreting

Procedure

Before you begin, read the Analysis questions and determine strategies you will use to identify parts of the video where useful information is located. View the video "Road Stories: Green Cities" on the Science 30 Textbook CD.

Analysis

1. Identify the natural resource that was chosen when the town of Okotoks established limits on its maximum size.
2. Describe some of the strategies used to ensure the long-term sustainability of the resource identified in your answer to question 1.
3. Identify the renewable-energy technologies used to meet the energy needs of municipal buildings in Okotoks.
4. Describe how the design of municipal buildings has allowed for renewable-energy technologies to be used.
5. Drake Landing Solar Community in Okotoks has taken a unique approach to utilizing the Sun's energy. Obtain the "Drake Landing Solar Community" handout from the Science 30 Textbook CD. Match the labels provided on the handout with locations on the diagram of the energy capture and distribution system used at Drake Landing.
6. Describe other features of the homes in Drake Landing Solar Community that enable them to reduce annual greenhouse emissions by 83%.
7. Sustainable development involves consideration of other aspects of human activity in addition to energy. Communities like Drake Landing Solar Community can be rated in terms of how close they come to perfectly illustrating sustainable development. A score of 10 out of 10 represents the ideal sustainable-development community, and a score of 0 represents the complete opposite.
   - **a.** List the activities designed to reduce environmental impact in which the citizens of Okotoks participate.
   - **b.** Determine a score out of 10 for the Drake Landing Solar Community in terms of its ability to incorporate sustainable development. Justify your score.
   - **c.** Determine a score out of 10 for the community where you live in terms of its ability to incorporate sustainable development. Justify your score.

Evaluating Energy Technologies for Sustainability

As you saw in the preceding activity, if a community like Okotoks pursues a community plan to promote sustainable development, access to sustainable sources of energy must be part of the strategy. How are decisions made when choosing one energy source—or a technology that uses that energy source—over another? What criteria could be used to compare different technologies and their sustainability?

The overall sustainability of an energy source is determined by examining its

- ecological sustainability
- societal sustainability
- economic sustainability

Ecological Sustainability

ecological sustainability: functioning in such a way as to not adversely affect air, water, land, biodiversity of organisms, or natural ecosystems

An energy technology demonstrates **ecological sustainability** if its use enables the protection of the three key components of the biosphere: land, water, and air. In addition, the use of the technology should maintain biodiversity, promote the survival of species at risk, and protect fragile ecosystems. It follows that environmental sustainability involves protecting organisms from the harmful effects of pollution and ionizing radiation. The following list of statements describes an energy source that supports ecological sustainability.

An energy technology that demonstrates ecological sustainability

- is based on a renewable energy source
- maintains the quantity of surface water
- maintains the quality of surface water
- does not contribute to acid deposition
- does not contribute to the presence of persistent organic pollutants in water, soil, or air
- does not contribute to the presence of heavy metals in water, soil, or air
- recycles liquid and/or solid waste products
- does not contribute to deforestation or habitat destruction
- does not contribute to greenhouse gas emissions
- does not contribute to emissions of ozone-depleting materials
- does not contribute to emissions of particulate matter
- does not contribute to photochemical smog
- does not threaten the survival of species at risk
- does not contribute to the destruction of fragile ecosystems
- does not contribute to the release of ionizing radiation
- does not contribute to the mass of radioactive waste produced

Societal Sustainability

In your studies throughout this course, you examined many technologies that convert energy from one form into other forms. Coal-fired power plants and nuclear power plants are two examples of energy technologies that generate electricity that, in turn, supports communities. Human communities can maintain themselves only if their populations have their needs met in terms of health and education. Sustainable societies ensure that people can support themselves with a reasonable standard of living so that families have access to affordable housing. A sustainable society is one that shows respect for the diversity of the cultural values within the community. The following statements describe aspects of **societal sustainability** in reference to how energy is provided.

societal sustainability: the ability of a group to support adequate living standards for its members; includes housing, health care, and respect and maintenance of cultural values

An energy technology that demonstrates societal sustainability

- does not decrease life expectancy through exposure to pollution
- stimulates a healthy economy, enabling adequate health care
- requires a highly trained workforce
- requires the workforce to adapt to change through continuous training
- reduces excessive land use (e.g., urban sprawl)
- encourages per capita energy consumption to be reduced
- stimulates a healthy economy, enabling affordable housing
- requires co-operation of diverse cultural groups in decision making

Economic Sustainability

Just as individuals need to provide for themselves economically, communities of people must be able to maintain economic activities over time. Indicators of **economic sustainability** include adequate employment opportunities for the population and opportunities for economic growth, which include goods and services that can add to the GDP. The following list of statements describes energy sources that support economic sustainability.

economic sustainability: the ability to provide employment opportunities and have access to goods and services in a manner that does not decrease the availability of natural resources

An energy technology that demonstrates economic sustainability

- supports full-time employment for the population
- enables a higher proportion of the workforce to be paid reasonable wages
- has a relatively low cost per megajoule (MJ)
- enables development of other industry or opportunity
- reduces the import of energy, contributing positively to the GDP
- enables the export of energy, contributing positively to the GDP
- can be used in a variety of locations that are well-suited to industry
- allows for continuous, around-the-clock production
- does not decrease the availability of natural resources

In the next activity you will have an opportunity to evaluate an energy resource for ecological, societal, and economic sustainability.

Try This Activity

Determining the Sustainability of Coal-Fired Power Plants

Science Skills

- ✓ Analyzing and Interpreting
- ✓ Communication and Teamwork

Purpose

You will use a detailed checklist to determine the sustainability of generating electricity using coal as a source of energy. You will then compare your results with other students.

Background Information

From your previous work in Units B and C, you are already quite familiar with coal as an energy source. In this activity you will rely on your knowledge of key concepts covered in this course to complete a checklist outlining criteria that are essential for ecological, societal, and economic sustainability. Completing the checklist will enable you to determine the sustainability of this technology.

Procedure

Obtain the document "Determining Sustainability of Technologies" from the Science 30 Textbook CD. Follow the instructions in the document to determine the overall sustainability of coal-fired power generation. **Note:** Keep your completed checklist because you will be asked to refer to it throughout this chapter.

Analysis

1. Justify the weightings you chose for each type of sustainability. Given the results of other students, would you revise your weightings if you were to repeat this activity?
2. Identify the sources responsible for the variability in the overall score for sustainability in this activity. Include an explanation as to why there is no "right answer" in terms of the overall score for sustainability for a given energy resource.

Making Sense of Sustainability Scores

You just determined the sustainability of coal-fired electricity generation. The point of the activity was not to arrive at a pre-determined "right answer," but rather to stimulate discussions with others and to validate the use of the checklist. These skills will be beneficial when determining the sustainability of other energy technologies. Even though individual students may not completely agree with the weightings for the categories of ecological, societal, and economic sustainability, the common sets of criteria shown in the checklist allow you and your classmates to compare various energy sources. Is it possible for other technologies to score higher than coal-fired power plants? Which technologies show the greatest potential for providing human communities with a sustainable future? The rest of this chapter will largely be focused on helping you answer these questions.

Practice

In Chapter 1 you discovered that CANDU reactors use nuclear fission to generate electrical energy.

Before completing questions 3 and 4, review the energy conversions and processes involved in the operation of a CANDU reactor.

3. Obtain the document "Determining Sustainability of Technologies" from the Science 30 Textbook CD. Follow the instructions in the document to determine the overall sustainability of nuclear fission as a source of electricity. **Note:** Keep your completed checklist for nuclear fission because you will be asked to refer to it throughout this chapter.

4. Compare your assessment of the sustainability of nuclear fission as a source of electricity with your evaluation for coal-fired electricity generation from the "Determining the Sustainability of Coal-Fired Power Plants" activity.

a. Identify which technology is more sustainable. Justify your selection.

b. Compare your answer to question 4.a. with other students. Did other students agree with your answer and your justification? Identify any major differences between conclusions and justifications.

Earth's Heat—Geothermal Energy

You may recall from previous science courses that geothermal energy is responsible for the movement of Earth's tectonic plates, in addition to other spectacular displays, like volcanic eruptions and geysers. The plumes of hot rock and lava sent into the air from active volcanoes or the periodic blasts of high-temperature water and steam from geysers originate from nuclear decay reactions that occur thousands of kilometres below Earth's surface.

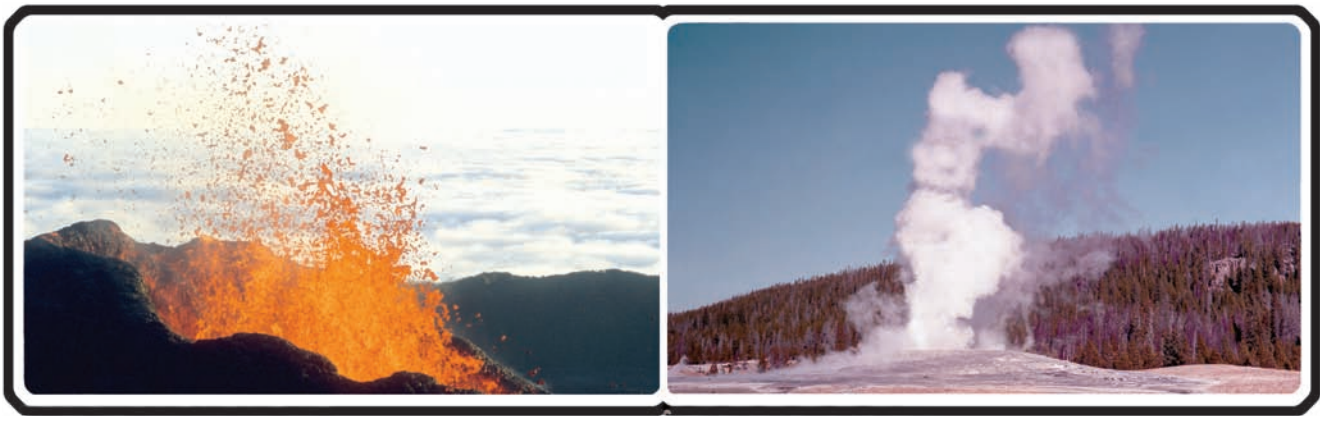
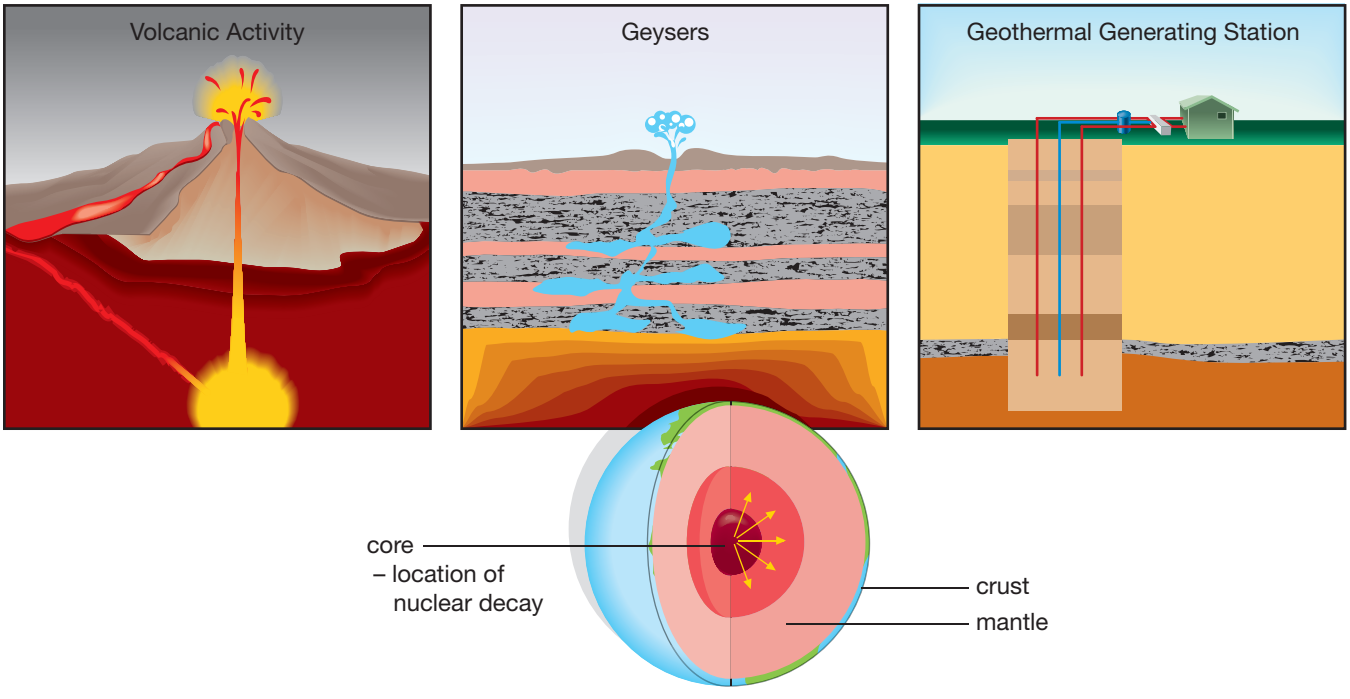


Figure D2.2: Volcanoes and geysers are examples of the large quantity of energy available from geothermal sources.

Evidence suggests that the radioactive decay of unstable isotopes within Earth's core helps maintain the temperature of Earth's inner-most layer at about 5000°C. Heat from the nuclear reactions in the core drives convection currents within the molten rock of the mantle—Earth's middle layer. These convection currents cause the crustal plates to move. **Geothermal energy** tends to collect at the boundaries between these plates where Earth's crust is thin or fractured. The condition of the crust at these boundaries often provides pathways for geothermal energy to reach the surface.

geothermal energy: heat that originates from radioactive decay in Earth's core

Geothermal Energy—Heat from Within Earth



DID YOU KNOW?

The decay of the isotopes potassium-40, thorium-232, uranium-235, and uranium-238 produce geothermal energy.

For individuals, industries, and governments around the world looking for ways to diversify energy and fuel production, geothermal energy may be an alternative. Despite the fact that the nuclear isotopes responsible for the production of heat are limited, current estimates predict they will not be depleted for millions of years.

Figure D2.3: Bathers in Iceland relax in natural hot water, which is the result of geothermal energy from deep within Earth reaching the surface. In the background is a large power plant that uses the geothermal energy to generate electricity.

Figure D2.4: Iceland's largest city, Reykjavik, uses sustainable geothermal energy to heat its buildings and generate its electricity.

Geothermal energy is used either for heating or generating electricity in over 30 countries around the world. In the Philippines, geothermal energy provides 27% of the country's electricity. In Iceland's capital city, Reykjavik, geothermal energy heats over 80% of the buildings and is used to generate nearly all of the electricity. In the United States, geothermal energy provides approximately $1 billion worth of electricity in California, Hawaii, Nevada, and Utah each year. In 2000, the United States' government set a goal to increase geothermal energy use from 0.45% to at least 10% of the electricity production in the western United States by 2020.

DID YOU KNOW?

Geothermal Electricity in Canada

Canada does not currently use geothermal energy to generate electricity. Areas with the greatest potential are found in British Colombia's coastal mountains. To date, the Meager Mountain area appears to hold the greatest potential for geothermal electricity. A 100-MW facility may eventually be built in this area.

Using Geothermal Energy

At first blush, geothermal energy seems to have some significant advantages as an energy source. Since Earth's energy can be used to produce pressurized steam, the need for fuels to heat water is eliminated. If it is possible to construct a generating station close to the fissure and to the source of hot water, electricity generation can be relatively inexpensive to set up and can be very efficient.

However, since geothermal generating stations often utilize steam from deep within Earth's crust, emissions of hydrogen sulfide, $H_2S(g)$, and carbon dioxide, $CO_2(g)$, often occur. Even though these emissions come from a natural source, they represent only a fraction of those from comparably sized fossil fuel-fired installations. As you determined in Unit B, $H_2S(g)$ and $CO_2(g)$ can react to form acids, causing corrosion of metals used in a geothermal facility and acid deposition within the surrounding area.

Perhaps the greatest drawback of geothermal energy is that it is a localized resource. It is only cost-effective in areas where geological hot spots already exist. Since many populated areas in the world are not located along the boundaries of crustal plates, geothermal energy is not a practical alternative.

DID YOU KNOW?

The mean temperature of Earth's crust increases by 3°C every 100 m as you move closer to the core.

The exception to this trend occurs in California. As you may recall, a large portion of California's population lives near the San Andreas Fault, close to the border between the North American Plate and Pacific Plate—which contains many geothermal hot spots. The transformation of geothermal energy in California made the United States the world's largest producer of electricity from geothermal sources in 2003. Other countries that are major users of this energy source include Iceland, the Philippines, Mexico, Indonesia, Italy, Japan, and New Zealand. In spite of what seems to be an ample supply of heat, geothermal hot spots can decrease in temperature if they are not properly managed and, thus, reduce the energy available for transformation.

DID YOU KNOW?

Sacred Waters

First Nations peoples have used hot springs for thousands of years. Many naturally heated waters have long been revered for their sacred, healing properties. First Nations people were the first to introduce European explorers to the Miette Hot Springs near Jasper.

Practice

5. Identify a way geothermal energy is used other than to generate electricity.
6. Identify which part of Canada is believed to have the greatest potential to exploit geothermal energy on a large scale. Concisely explain why.
7. Identify two advantages and two disadvantages of geothermal energy.
8. Obtain the document "Determining Sustainability of Technologies" from the Science 30 Textbook CD. Follow the instructions in the document to determine the overall sustainability of geothermal energy as a source for producing electricity. **Note:** Keep your completed checklist for geothermal energy because you will be asked to refer to it throughout this chapter.

Tidal Energy

Figure D2.5: It's low tide at Alma Harbor, New Brunswick, on the Bay of Fundy. The highest tides in the world occur in the Bay of Fundy, located between New Brunswick and Nova Scotia.

Although it may appear that some form of natural disaster has left these fishing boats stranded, their position is due to the cycle of the **tide** in the Bay of Fundy. The extreme tides in this area are due to the way water moves—because of the unique shape of the bay and the natural cycle of the tides. The result is an effect similar to pushing a child on a swing, amplifying the energy of the original movement. Oceanographers have determined that the energy within a wave entering the Bay of Fundy returns to the mouth of the bay in just under 13 hours.

tide: the deformation of land and water due to the gravitational fields of the Moon and Sun acting on every part of Earth

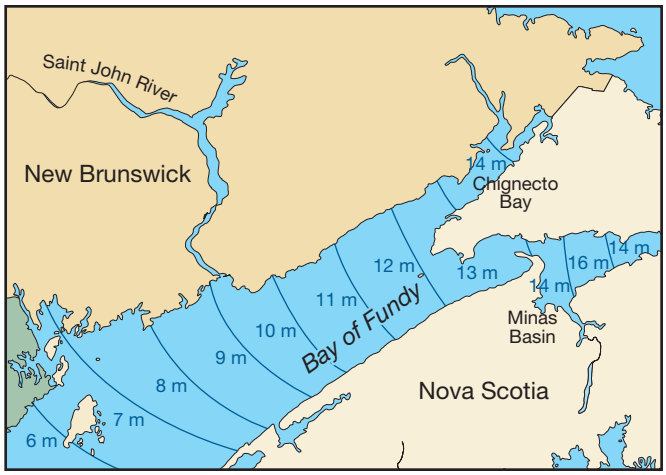
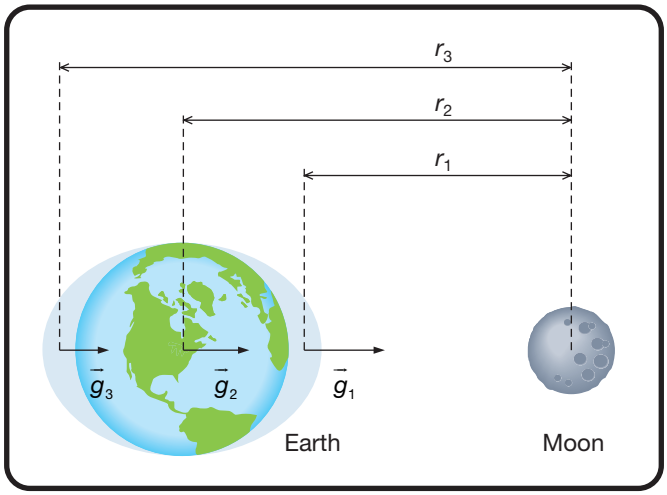


Figure D2.6: This map of the Bay of Fundy shows the difference between high tide and low tide for various locations.

Since the time between one high tide and the next is 12 hours 25 minutes, the rhythm of Earth's tides is precisely tuned to this particular bay. The natural frequency of the movement of water in the bay becomes amplified by the energy in the pulse of the tides. Why is the time between adjacent high tides exactly 12 hours 25 minutes?



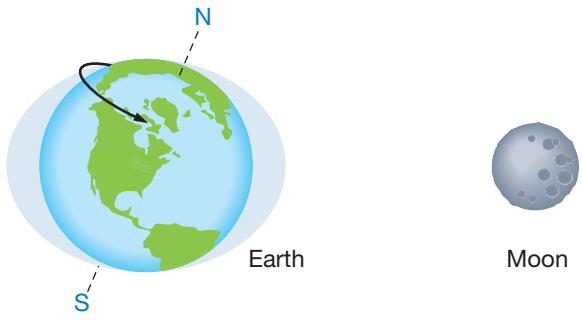
Tides are the result of the gravitational fields of both the Sun and Moon acting on every part of Earth. Recall from Unit C that the gravitational field of a source weakens as the distance from the source increases. Since the Moon is closest to Earth, it accounts for most tidal effects. The explanation provided in this course will focus only on the effects of the Moon on tidal patterns.

As mentioned in Unit C, a field is defined by the behaviour of a test object within it. In a tidal system, the Moon is the source of the gravitational field and the test object is Earth's water. Since approximately 70% of Earth's surface is water, two portions of Earth are considered when analyzing tides: the water on the side of Earth closest to the Moon and the water on the side of Earth farthest from the Moon. Also, the mass of Earth must be considered when analyzing this system.

The water on Earth's surface closest to the Moon is subjected to the strongest gravitational field, $\vec{g}_1$. The centre of Earth is farther from the Moon, so the Moon's gravitational field, $\vec{g}_2$, is weaker compared to the force $\vec{g}_1$. The slight difference between these two forces distorts Earth's shape and causes the water to form a tidal bulge on the side closest to the Moon.

The difference between the gravitational field acting on the far side of Earth, $\vec{g}_3$, and the field acting on the centre of Earth, $\vec{g}_2$, accounts for the bulge on the side of Earth farthest from the moon. Since the centre of Earth experiences a gravitational attraction to the Moon larger on the far side, the difference between these two forces distorts Earth's shape. In a sense, the centre of Earth is "pulled away" from the water on the far side leaving a tidal bulge.

Earth's Rotation Through Tidal Bulge



As Earth spins on its axis, each part of the planet along a sea coast moves through two areas of high tide and two areas of low tide every 24 hours 50 minutes. The extra 50 minutes is needed to make up for the Moon's motion. The Moon takes an extra 50 minutes each day to return to its highest point in the night sky (as observed from a location on Earth).

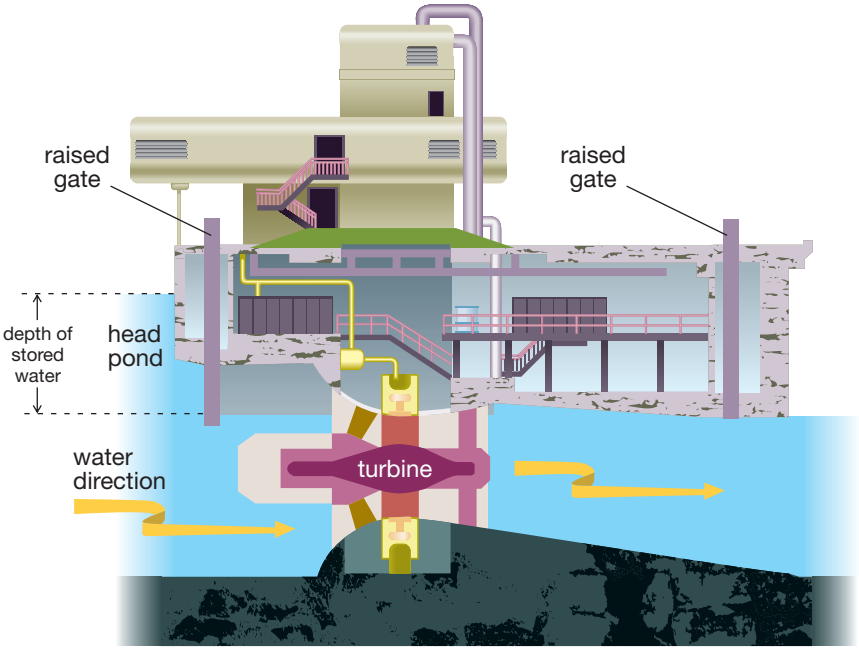
Figure D2.7: In Nova Scotia, tidal bore rafting has become a popular recreational experience. The rapids are created when incoming tidal water collides with outgoing river water.

Using Tides to Generate Electricity

At all locations around the Bay of Fundy, massive amounts of water move in and then retreat. As the water reaches its higher level in the daily tidal cycle, it possesses increased gravitational potential energy, in contrast to its kinetic energy when it flows between high and low tide. The potential and kinetic energy associated with the rise and fall of water during ocean tides is known as **tidal energy**.

tidal energy: the gravitational potential energy and the kinetic energy of ocean water generated by tidal effects

Cross Section of Tidal Station



To harness tidal energy, a special type of barrier—often called a barrage—is constructed. When the tide comes in, electricity is generated as water flows through the turbines housed within the barrage. Water that has passed through the barrage is held in the estuary behind the barrage by gates. The gates act like valves in veins, preventing a backflow of water until it can be used to generate electricity. To generate electricity after high tide, the water held in the estuary is released through channels, flowing past the turbines connected to the generators. The Annapolis Tidal Station (seen in the photo below), located in the Bay of Fundy, generates 20 MW of electricity daily.

Assessing Tidal Energy

Like geothermal energy, tidal energy is a renewable resource. The energy of the water flowing through the turbine within the barrage is due to the potential and kinetic energy of the Earth-Moon system. Appropriate conditions for the conversion of tidal energy—a 5-m difference between low tide and high tide—only occur in a few localized areas. Even if these conditions can be met, the fact that high tides are spaced over 12 h apart means that energy from tides is only available at certain times; it is not available on a constant basis.

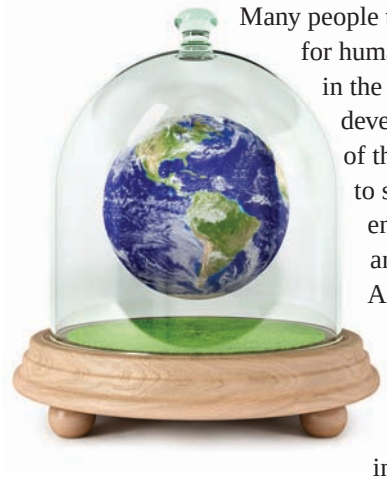
From an ecological point of view, tidal energy may appear to be a strong option because it does not involve the combustion of a fuel or produce harmful emissions. However, the presence of the barrage across the estuary could affect the ecology of the estuary—for example, it could interfere with the migration routes of fish.

Practice

9. Explain why the Bay of Fundy is one of the world's most promising tidal energy sites.

10. Obtain the document "Determining Sustainability of Technologies" from the Science 30 Textbook CD. Follow the instructions in the document to determine the overall sustainability of tidal energy as a source for producing electricity. **Note:** Keep your completed checklist for tidal energy because you will be asked to refer to it throughout this chapter.

2.1 Summary



Many people think that it is imperative for human communities to move in the direction of sustainable development. A cornerstone of this approach is for people to seek energy sources that ensure ecological, societal, and economic sustainability. Although there may be consensus that each of these categories is important, there is considerable variability in terms of the weightings that should be assigned to each category. This leads to a wide spectrum of opinions when it comes to evaluating conventional energy sources, like coal, as well as alternative energy sources, like geothermal and tidal energy.

2.1 Questions

Knowledge

1. Define the following terms.

- **a.** sustainable development
- **b.** geothermal energy
- **c.** tidal energy

2. Describe the energy transformations that occur to produce electricity from each of the following sources. Begin with the original source of the energy and finish with the electricity produced.

- **a.** geothermal energy
- **b.** tidal energy

3. Explain the classification of each of the following processes as being either renewable or non-renewable.

- **a.** combustion of coal
- **b.** fission of uranium-235
- **c.** fission of isotopes in Earth's core
- **d.** movement of water in ocean tides

Applying Concepts

4. When energy is converted from one form into another, some of the energy is always lost. Use this idea to comment on the efficiency of a geothermal electrical generating station as compared to a coal-fired electrical generating station.

Earlier in this chapter you completed the "Determining Sustainability of Technologies" checklist to determine the sustainability of generating electricity using the following energy sources: coal energy, nuclear energy (fission), geothermal energy, and tidal energy. Review your completed checklists; then answer question 5.

5. Prepare a table that ranks the four methods from most sustainable to least sustainable. Support your ranking by writing a brief summary.